

BALLISTIC PROTECTIVE ARMOUR AND BALLISTIC PROTECTIVE HELMET AND PROTECTIVE VEST

The present invention relates to ballistic protective armour according to the preamble of claim 1, and a corresponding ballistic protective helmet and protective vest.

Ballistic protective armour of this type is a component of ballistic protective clothing or head coverings such as military helmets, bullet-proof vests and suchlike. For reasons to do with saving weight, such protective armour is generally made from technical fabrics such as high-molecular polyethylene, aramid or other highly durable yarns. Individual layers of fabric are laminated with the help of an adhesive matrix by applying an adhesive, a resin or a film between the individual textile layers, and the entire packet of layers is then pressed to create a textile laminate.

The properties of the protective armour may be varied as a function of the material properties of the yarns used for the textile layers, the different types of weave and fabric weights, and the percentage of resin or adhesive in the connection matrix. Besides form stability, i.e. resistance to deformation, which is particularly important in protective helmets, resistance to an impacting projectile or fragments naturally plays a primordial role. In addition to exerting force in the layering direction, which will be referred to below as the Z direction, the impacting missile also exercises forces in the directions within the plane of the layers, i.e. in the X and Y directions perpendicular to the Z direction. These forces are absorbed by the yarns or fibres of the textile layers, whilst the forces in the Z direction are absorbed by the bonding of the textile layers. This means that the adhesive strength of the matrix makes a decisive contribution to preventing the missile from penetrating the armour.

It is possible to completely embed the layers of textile fabric in the matrix so that the adhesive force holding the layers to each other is very high. In general, the forces occurring in the X and Y directions upon impact of a missile cause the fabric fibres to stretch, thereby absorbing energy. As this happens, the protective armour may bulge in the direction of impact. If, however, a certain force or extension of the fibres is exceeded, the fibres are

1 abruptly sheared and the missile penetrates the corresponding layer. This
shearing effect is exacerbated by completely embedding the fabric in the
resin or adhesive matrix as this restricts the fibres in their capacity for
longitudinal extension. This reduces resistance to perforation of the armour.
5 Besides this effect, a high percentage of resin or adhesive increases the
weight of the protective armour.

Attempts have therefore been made to construct ballistic protective armour
with a reduced application of resin between the textile layers. This saves
10 weight, and the energy absorption within the individual textile layers is
increased as the fabric fibres not embedded in the matrix can stretch
unhindered. On the other hand, the hold between the layers is reduced.
Hence the following effect occurs upon impact of a projectile: as a result of
the shearing effect, the outer textile layers are smoothly penetrated by the
15 projectile, which is greatly deformed in the process. The following layers stop
the projectile, whose kinetic energy is already greatly reduced by this point,
thanks to the stretching of the fibres within the textile layers. As this
happens, these stopping layers of the laminate bulge substantially towards
the inside of the protective armour because the projectile-stopping layers
20 detach more easily from the perforated layers due to the reduced application
of resin, and delamination occurs between these layers. The pronounced
bulging effect can, however, cause serious injury to the wearer of the ballistic
protective clothing. The wearer of a ballistic protective helmet which is
subjected to substantial inward deformation upon impact of a missile may,
25 for example, suffer head injuries.

When designing conventional ballistic protective armour one must, therefore,
prevent the above described effect of complete perforation on the one hand,
whilst also preventing excessive deformation of the inner layers of the textile
30 laminate on the other hand. This is done by appropriately matching the
stretch properties of the textile fabric and the percentage of resin or
adhesive, so that the load uptake in the various directions can be
predetermined. This is only possible to a limited extent, however, because the
conditions are difficult to reproduce during production of the protective
35 armour, and because the delamination effect that occurs as the deforming
stopping layers detach from the perforated layers is sudden and virtually
uncontrollable. These circumstances render it extremely difficult to select, in

1 particular, the percentage of resin or adhesive to use in the connection matrix.

5 The task of the present invention is therefore to provide ballistic protective armour of the above-mentioned type which reliably prevents penetration by projectiles or impacting fragments but at the same time reduces the above-described deformation effect on the inside of the armour opposite the impact side to an acceptable degree, whilst keeping the weight of the protective armour as low as possible.

10 This task is solved according to the invention by means of ballistic protective armour with the features of claim 1.

15 The ballistic protective armour according to the invention comprises a number of wire or thread binders which pass through the textile laminate in the layering direction, i.e. in the direction of the surface normals, which is perpendicular to the textile layers. These binders give the individual textile layers of the laminate additional hold relative to each other in that in addition to the prior art adhesive matrix, a further mechanical connection is
20 created. By selecting an appropriate tensile strength, i.e. elasticity, of the binders it is possible to improve the perforation and deformation properties of the textile laminate and its resistance to an impacting projectile.

25 In particular, the above-described bulging effect in the inner stopping layers of the laminate which are deformed on projectile impact is greatly reduced as the binders can absorb large tensile forces in the direction of the missile, and can prevent an uncontrolled detaching of the layers from each other (delamination). Instead, the delamination effect is restricted to the immediate vicinity of the missile channel. In this region the tensile forces on the binders
30 are so high that they break and the inner stopping layers can become detached. In the directions within the layers, i.e. in the directions perpendicular to the layering direction, the force finally decreases until it drops below the force required to snap the binders, so that the binders are merely stretched. The adhesive coatings on the layers may become detached
35 from each other, but the layers themselves are held together in a stable manner by the stretched binders. This substantially reduces the degree of inward bulging in the protective armour, and hence the risk of injury. And

1 there is still sufficient absorption of the kinetic energy from the missile to
ensure that the projectile is unable to completely penetrate the textile
laminate. The percentage of resin or adhesive in the textile laminate can be
5 substantially reduced without excessive deformation occurring, which results
in weight savings and improved wearer comfort.

Advantageous embodiments of the ballistic protective armour according to
the invention are disclosed in subclaims 2 to 18.

10 A ballistic protective helmet, whose helmet shell is formed by ballistic
protective armour according to the invention, is claimed in claim 19.

Claim 20 is further directed at a ballistic protective vest comprising hard
segments or hard inserts, each of which is formed by ballistic protective
15 armour according to the invention.

Further embodiments of this protective vest are disclosed in claims 21 and
22.

20 Preferred examples of embodiments of the invention will be described in more
detail below with reference to the drawings, in which

Fig. 1 shows a side partial section through a ballistic protective
helmet whose helmet shell is formed by ballistic protective
25 armour according to the invention;

Fig. 2 shows a top plan view of a section of the surface of the helmet
shell of Fig. 1;

30 Fig. 3 shows a partial section through a helmet shell according to a
further embodiment of the invention;

Fig. 4 shows a top plan view of a section of the helmet shell of Fig. 3;

35 Fig. 5 shows the helmet shell of Fig. 3 in a deformed state after impact
by a projectile, and

1 Fig. 6 shows a partial section through a helmet shell according to a
 third embodiment of the invention.

5 The helmet shell 10 shown in Figure 1 is a component of a ballistic protective
 helmet, for example a helmet for military use. The concave inside of the
 protective helmet closest to the helmet wearer's head (not illustrated) is
 shown at the bottom of the Figure, whilst a projectile may impact from the
 convex outer side. The term "projectile" as used hereafter includes all
10 possible ballistic missiles, such as grenade or missile fragments or suchlike
 in addition to projectiles from firearms in the narrowest sense.

 Other devices inside the protective helmet such as a basket-shaped lining
 attached to the inside of the helmet shell 10, which ensures a gap between
 the helmet wearer's head and the inside of the helmet shell 10 and improves
15 wearer comfort, is not shown in this or any of the following figures.

 Figure 1 shows the helmet shell 10 in intact condition. It is formed by
 ballistic protective armour 12 comprising a textile laminate 14 made from a
 number of textile layers which are laminated together. The layers run along
20 the curve of the helmet surface, parallel to each other, between the inner and
 outer surfaces of helmet shell 10, i.e. the layering direction coincides with
 the surface normals, which is perpendicular to the surfaces of the textile
 layers. In Figure 1, the layering direction is designated by an arrow Z, which
 coincides with the normals of the outer helmet surface at a certain point of
25 curvature, whilst the individual textile layers run in the X and Y directions
 inside helmet shell 10, perpendicular to layering direction Z. For the sake of
 completeness, the X direction (to the right in Figure 1) is also indicated by an
 arrow X.

30 For reasons of clarity, the textile layers are shown in cross-section in a
 region confined to the right of the Figure. The layers actually run through the
 entire helmet shell 10. The present embodiment specifically includes ten
 layers 16 to 34, layered on top of each other in the Z direction. In practice it
 is usual to use an even larger number of layers; the person skilled in the art
35 will, however, be able to select an appropriate number of layers. Each of
 textile layers 16.....34 comprises a fabric made of aramid, polyethylene or
 carbon fibres, that is a synthetic material with high tensile strength in the

1 directions X and Y, in which the layer stretches. It is further possible to weave the textile layers out of yarns, or to produce them using other textile techniques.

5 Textile layers 16.....34 are laminated together in that they are pressed with a connection matrix disposed layer by layer between the individual textile layers. This connection matrix may be, for example, an adhesive, a resin or a pressable film. To produce the textile laminate 14, textile layers 16.....34 and adhesive or resin layers, or film layers, are thus alternately positioned one on

10 top of the other and pressed under high pressure so that the textile laminate 14 is created as a composite made of textile layers and the connection matrix. The individual layers of the connection matrix are not shown in more detail in Figure 1 or the following Figures. The stability of this packet of layers 14, i.e. its resistance to forces in the Z direction, which act to detach

15 textile layers 16....34 from each other, and the weight of helmet shell 10 can be determined by the quantity of adhesive or resin applied, or the thickness of the pressable film between the textile layers. Basically, the greater the weight percentage of the connection matrix in relation to the total weight, the greater its strength, meaning that the strength can be increased by, for example, applying more resin. Doing so may, however, cause an effect whereby the material used for the connection matrix penetrates at least partially into the fabric of the textile layers 16...34 when the laminate is pressed, causing the fibres of the textile layers to become embedded in the matrix. This severely restricts the fibres' ability to stretch in the X and Y

20 directions.

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According to the invention, the ballistic protective armour 12 forming helmet shell 10 comprises a number of wire or thread binders 40, which pass through the textile laminate 14 in the layering direction Z from the inner

30 surface of helmet shell 10 to the outer surface, i.e. through all the textile layers 16....34. These binders, which are spaced apart from each other in directions X, Y in which textile layers 16...34 run, ensure additional hold between the textile layers 16....34. Hence layers 16....34 are not held together solely by the adhesive force of the connection matrix, but also

35 mechanically, by binders 40. This ensures greater stability of laminate 14 in the layering direction Z and, in the event of impact by a projectile, offers

1 advantageous properties in case of delamination of the inner textile layers, as
will be described in more detail below.

Binders 40, of which only the left-hand binder 40 is provided with a reference
5 numeral in Figure 1, can be made of any suitable material which exhibits the
desired properties, i.e. appropriate tensile strength and elasticity in
particular. Binders 40 may, for example, be made of a metal or a synthetic
material, and possibly flexible reinforcing threads formed from a single fibre
or a number of fibres which may further be spun or drilled to form a yarn.
10 Highly durable materials such as aramid, polyethylene or carbon fibres are
possibilities. Although not shown in Figure 1, it is conceivable that the ends
of the individual binders 40 on the outside and inside of helmet shell 10 be
provided with anchoring devices such as protuberances or suchlike to
prevent binders 40 from simply being pulled out of the packet of layers in the
15 event of delamination of the textile laminate 14.

To allow binders 40 to fulfil their function according to the invention it is not
essential that binders 40 run precisely in the layering direction Z or $-Z$, i.e.
in the direction of the surface normals of textile layers 16....34 at the point
20 of penetration of binders 40, rather it is sufficient that the stretching
direction of binders 40 includes a component which coincides with the
layering direction Z , so that textile layers 16....34 are penetrated. Hence it is
permissible to include a certain angle with the normals. If such deviations
are desired for constructive reasons, the person skilled in the art will be able
25 to determine a suitable size for the angle of deviation through tests not
involving a great deal of work.

Figure 2 shows a top plan view of helmet shell 10 with the inserted binders
40. In this figure all that is visible is a section of the surface of the
30 uppermost textile layer 34, inside which lie the outermost ends of the wire or
thread binders 40. The layering direction Z thus points out of the plane of
the drawing in Figure 2. Binders 40 are arranged in a regular quadratic grid
pattern, i.e. binders 40 are disposed in both the X and Y directions to
coincide with the stretching direction of textile layer 34, positioned in rows at
35 equal distances, a , from each other. Distances a may be freely selected in
order to influence the stability of the textile laminate 14 and its delamination
behaviour.

- 1 Figure 3 shows a lateral partial section through another helmet shell 50
which is also made from a textile laminate 14 comprising individual textile
layers 16...34. The structure of the individual layers 16....34 made from a
highly endurable fabric, their layering in the Z direction and their connection
5 by means of layer-upon-layer pressing with a connection matrix correspond
to the helmet shell 10 of Figures 1 and 2, so that reference is made to the
preceding sections of the description with regard to the structure of textile
laminate 14.
- 10 According to the invention, helmet shell 50 comprises thread binders formed
here by sections 52, running in the layering direction Z, of a reinforcing
thread 54 which runs as an endless thread between the inner and outer
surfaces of helmet shell 50 meandering through textile laminate 14 in
direction X, i.e. in the direction in which textile layers 16...34 stretch.
15 Starting out on the left-hand side of Figure 3, a section 52 of reinforcing
thread running in layering direction Z initially passes from the inside to the
outside where it is joined by a connecting section 56, which rests on top of
the outer surface of helmet shell 50, of reinforcing thread 54. This is in turn
followed by a reinforcing thread section 52 which runs from the outside to
20 the inside (opposite direction -Z), followed by a connecting section 56 which
rests against the inside of the helmet shell. From here on, this sequence of
sections of the reinforcing thread 54 between the inside and the outside
repeats itself continuously in the stretching direction X of the textile layers
16.....34. Hence the individual reinforcing thread sections 52 forming the
25 binders are connected by connecting sections 56 to form an endless thread
which creates a seam which can run through the entire textile laminate 14
and helmet shell 50. Reinforcing thread 54 can be pulled taut to give the
individual textile layers 16...34 increased stability.
- 30 Reinforcing thread 54 may be a textile fibre made from a highly durable
synthetic material such as aramid, polyethylene or carbon fibre, and several
fibres of reinforcing thread 54 can be spun or drilled together to form a yarn.
Basically, the same materials can be used for binders 40 in the first
embodiment and for reinforcing thread 54, respectively sections 52 of it
35 acting as binders. Given that, in the case of the endless reinforcing thread
54, the thread path undergoes deflections at the inner and outer surfaces of

1 helmet shell 50, the thread material needs to exhibit a certain pliancy and flexibility.

Figure 4 shows a top plan view of a section of the outermost textile layer 34
5 from the same perspective as in Figure 2. Resting on the surface of the textile layer 16 one can recognise connecting sections 56 of reinforcing thread 54, whilst at the ends of connecting sections 56, reinforcing thread sections 52 run in the layering direction and opposite thereto (directions Z and -Z) into textile laminate 14 and out again. In Figure 4, the seams of endless threads
10 54 run from left to right, and connecting sections 56 are the same length on the inside and outside of helmet shell 50. Endless threads 54 are spaced apart in the direction perpendicular to the direction in which the seams run, and connecting sections 56 of adjacent connecting threads 54 are each staggered by the length of one connecting section 56 in relation to each other
15 in the direction in which the seams run.

It is understood that a different seam path may also be selected, for example by forming loops within the path of reinforcing thread 54, as will be explained below. Furthermore, as in the previously described embodiment, it
20 is not necessary for reinforcing thread sections 52 to run precisely in the direction of the surface normals; deviations from this direction can be tolerated. For example, consecutive reinforcing thread sections 52 may be inclined in relation to each other such that a W or zigzag type path results in the perpendicular sectional plane through laminate 14.

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Figure 5 shows the functioning principle of the ballistic protective armour according to the invention with reference to the second embodiment depicted in Figures 3 and 4. In this case it is assumed that helmet shell 50 is shot at with a projectile 60 which impacts absolutely perpendicular to helmet shell
30 50, i.e. in a missile direction -Z. Upon impact projectile 60 penetrates a number of outer textile layers, whereupon the fibres inside the textile layers are sheared smoothly, producing an approximately cylindrical missile channel 62. The projectile 60 is greatly deformed as this happens and its kinetic energy is partially absorbed until the energy is no longer sufficient to
35 penetrate further layers. This causes a deformation in the form of an inward bulge in the remaining textile layers on the inside of helmet shell 50 because the remaining energy from projectile 60 stretches the fibres of the textile

1 layers which are not penetrated. Projectile 60 then remains inside a cavern
64 between the outer and inner textile layers. This cavern 64 is formed
because the outer penetrated textile layers essentially retain their outwardly
curved shape whilst the deformation of the inner layers causes a detaching
5 or delaminating effect in that the outer and inner layer packets become
detached from each other in the vicinity of missile channel 62.

In Figure 5, the three outermost textile layers 30,32,34 are smoothly
penetrated and missile channel 62 forms inside them whilst the four
10 innermost layers 16 to 22 bulge inwards. The fabric of these textile layers 16
to 22 remains intact, the fibres of the fabric are merely stretched so that the
bulge is formed towards the inside of helmet shell 50. Between the
penetrated layers 30,32,34 and the deformed layers 16 to 22, which are also
referred to as stopping layers, there are three textile layers 24,26,28 which
15 are destroyed in the immediate vicinity of missile channel 62, absorbing
energy as a result.

When stopping layers 16 to 22 detach, the inner stability of textile laminate
14 provided by the connection matrix is destroyed and there is a risk that
20 uncontrolled detaching of the layers may cause substantial bulging and
hence injury to the helmet wearer. According to the invention, this
disadvantageous effect is prevented by reinforcing thread 54. The sections 52
of reinforcing thread 54 running in the layering direction Z are able to absorb
the tensile forces occurring in the Z direction upon impact, which stretches
25 reinforcing thread 54 along sections 52, so that additional energy is
absorbed. If the forces exceed a certain value, reinforcing thread section 52
snaps. As the force decreases in the lateral direction, i.e. in the X and Y
directions in relation to the direction of the missile, this snapping effect only
occurs in the vicinity of the missile channel 62, as shown in Figure 5.
30 Further away from missile channel 62 the tensile forces decrease and can be
absorbed by the sections 52 of reinforcing thread without snapping thread
54. In this fashion the adhesive layer of the connection matrix between the
penetrated layers 30,32,34 and the stopping layers 16 to 22 can be prevented
from giving way uncontrollably. The reinforcing thread sections 52 at the
35 outer regions of cavern 64 reliably limit the delamination effect. The
absorption of the tensile forces by the reinforcing thread sections 52 is
facilitated by the outer ends of sections 52 being anchored in the outer

1 textile layers 30,32,34 which retain their curved shape and hence exhibit
high stability against the tensile forces exerted by reinforcing thread sections
52. This anchoring effect in the outer layers 30,32,34 gives greater stability
to sections 52, and hence to the inwardly deformed region of the inner
5 stopping layers 16 to 22.

It is understood that the effect of the binders according to the invention as
shown in Figure 5 is illustrated through reinforcing thread sections 52
merely by way of example, and is similarly achieved by all kinds of binders as
10 defined in the present invention, in particular by binders 40 according to the
first embodiment.

The energy absorption within textile laminate 14 can be advantageously
increased by configuring the outer layers 30,32,34 in which missile channel
15 62 is formed to be very hard in comparison to the subsequent middle layers
24,26,28 which are destroyed in the region of cavern 64, thereby absorbing
energy. The great hardness of outer layers 30,32,34 greatly deforms projectile
60, which has to form a larger penetration channel to allow it to penetrate
more deeply into textile laminate 14. In order to guarantee good
20 deformability, the hardness of stopping layers 16 to 22 on the inside of
helmet shell 50 should advantageously be selected so that it lies somewhere
between the hardness of outer layers 30,32,34 and that of the soft middle
layers 24,26,28. The hardnesses of the various layers 16...34 can be
influenced by the choice of fabric, and in particular, by the percentage of
25 resin or adhesive in the connection matrix in the textile layers 16...34.

Finally, Figure 6 shows a helmet shell 70 similar to the helmet shell 50 of
Figures 3 to 5, in which the seams of reinforcing threads 54 follow a different
path. On the opposite surfaces of textile laminate 14, reinforcing threads 54
30 run as endless threads, of which each endless thread comprises a number of
loops 72 projecting into textile laminate 14, said loops being interlooped with
the loops 72 of an endless thread running across the opposite surface of
textile laminate 14. That means loops 72 of the reinforcing thread 54 that
rests against the outside of helmet shell 70 point into textile laminate 14
35 counter to layering direction Z through a channel not shown in more detail
and in the region of the middle textile layers engage in the loops 72 of
another endless thread 54 running in a similar manner along the inside of

1 the helmet. Each pair of interlooped loops 72 therefore forms a binder according to the invention. The loops 72 can be tensioned more or less tautly to permit adjustment of the elastic properties of the tensioning.

5 Ballistic protective armour 12 of the type described here is suitable not only for helmet shells 10,50 of ballistic protective helmets, but also for other kinds of ballistic protective clothing, in particular for protective vests designed to protect their wearer from projectiles or fragments. As such protective vests need to exhibit a certain flexibility for reasons to do with

10 wearer comfort, the prior art vests usually include hard segments or hard inserts at points which are particularly at risk. These hard segments or inserts can also be formed from the ballistic protective armour according to the invention. To guarantee unbroken protection without restricting the vest wearer's freedom of movement it is advantageous to select an arrangement

15 whereby the hard segments or hard inserts overlap each other, but can be displaced with respect to each other, or engage with each other.

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